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(54) DOUBLE SIDED HEAT SINK WITH MICROCHANNEL COOLING

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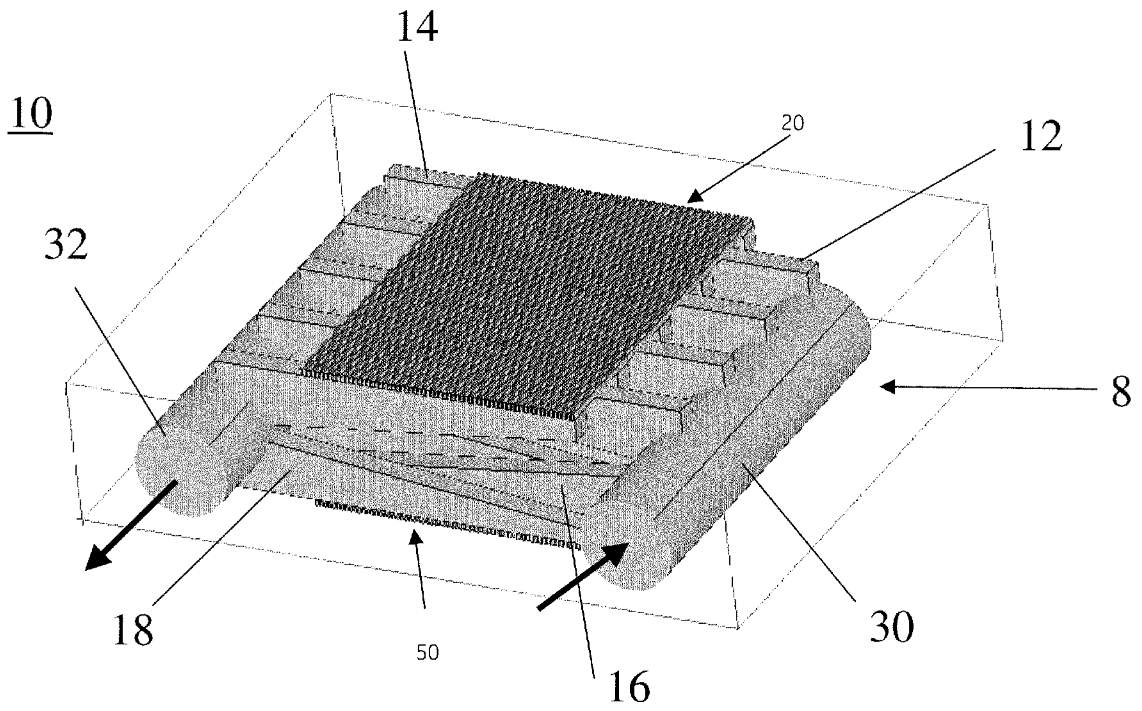
(57) ABSTRACT

An apparatus for cooling at least two heated surfaces includes a base plate defining multiple upper and lower supply manifolds and upper and lower exhaust manifolds. The upper and lower supply (exhaust) manifolds receive (exhaust) coolant, and the upper (lower) supply and exhaust manifolds are interleaved. The apparatus further includes an upper substrate having an inner surface and an outer surface. The inner surface is coupled to the base plate and defines multiple microchannels for receiving and exhausting coolant. The outer surface is in thermal contact with one of the heated surfaces. The apparatus further includes a lower substrate having an inner surface and an outer surface. The inner surface is coupled to the base plate and defines multiple microchannels for receiving and delivering coolant. The outer surface is in thermal contact with another of the heated surfaces. The apparatus further includes a supply plenum and an exhaust plenum oriented in a plane of the base plate.



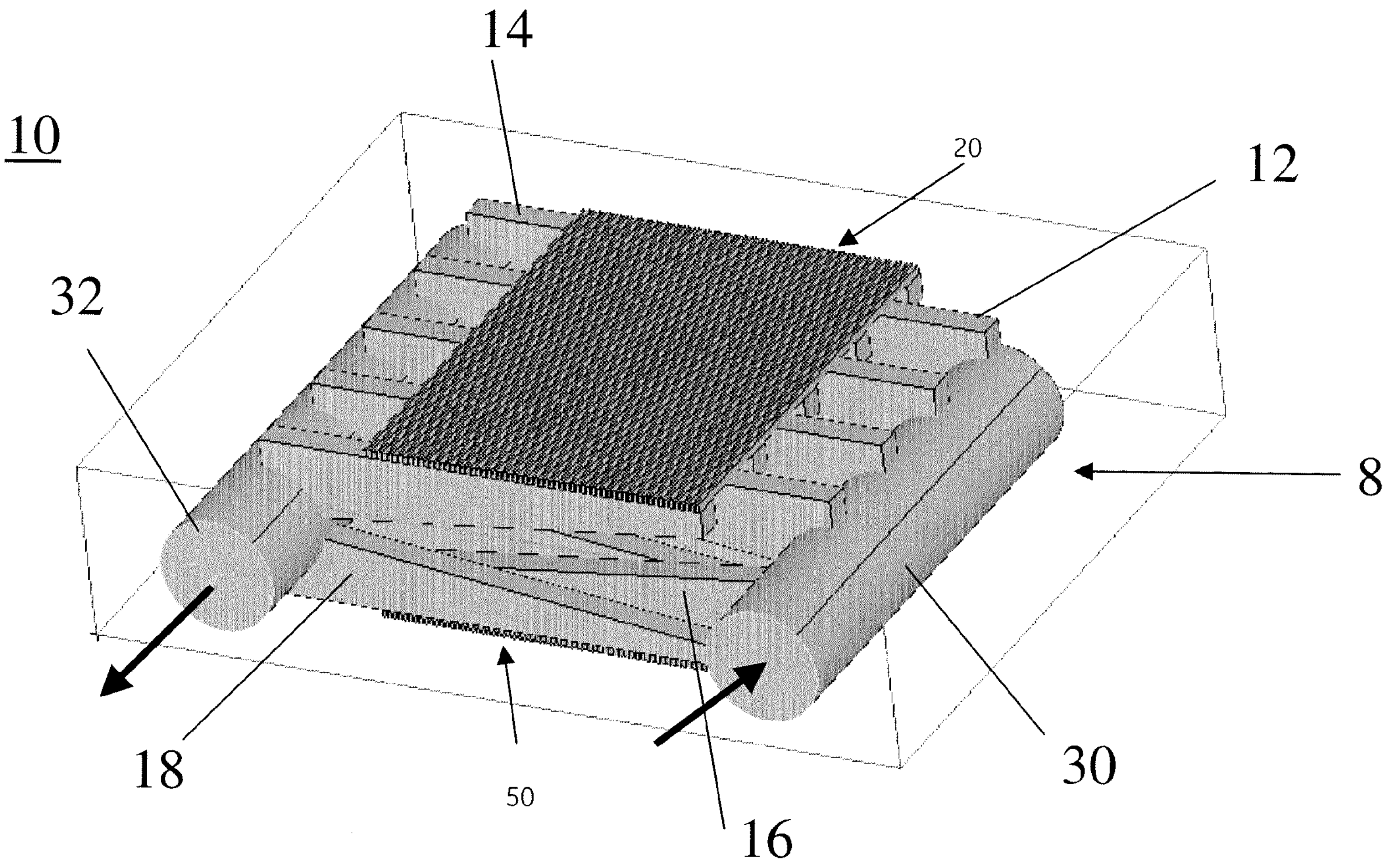


FIG. 1

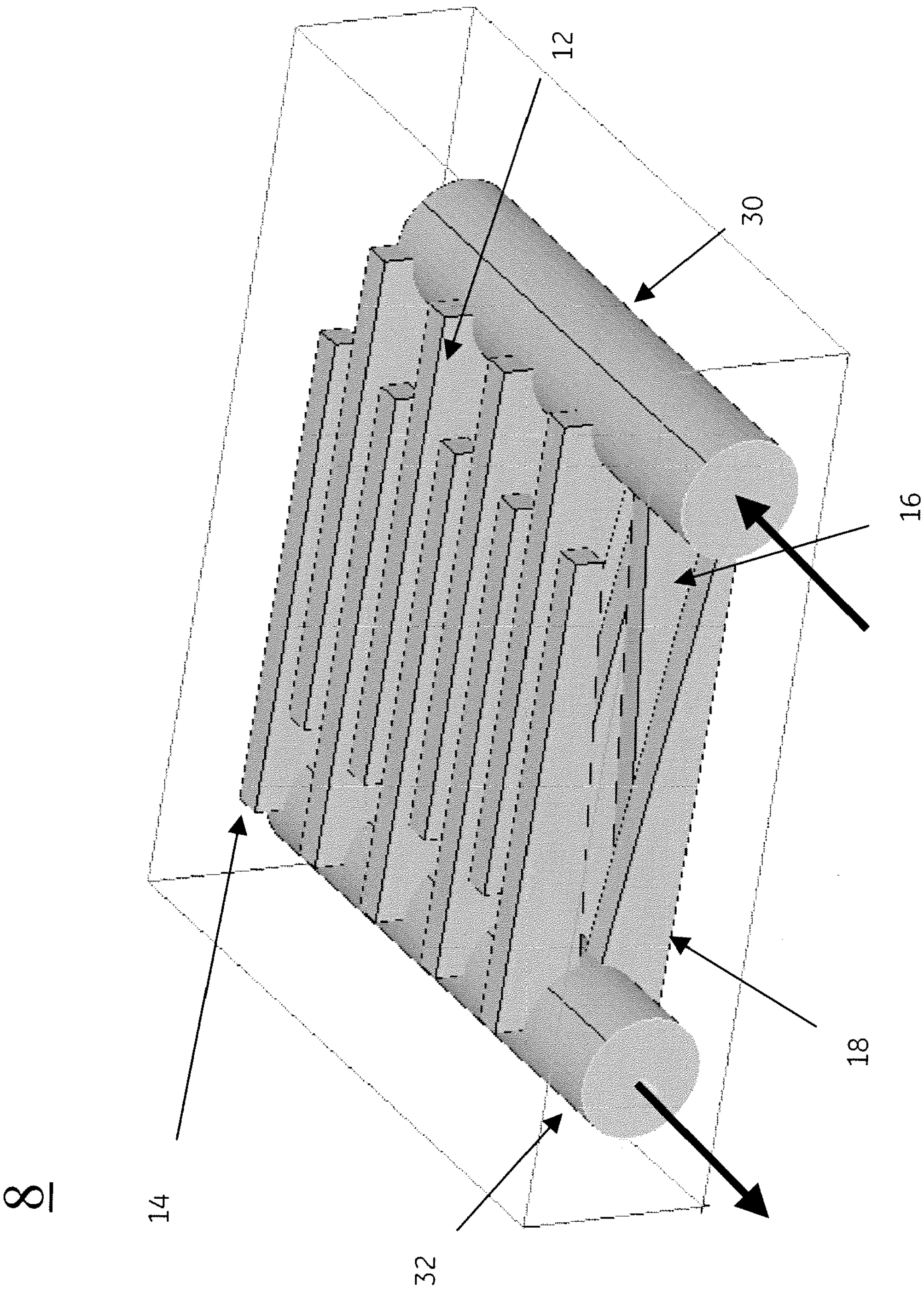


FIG. 2

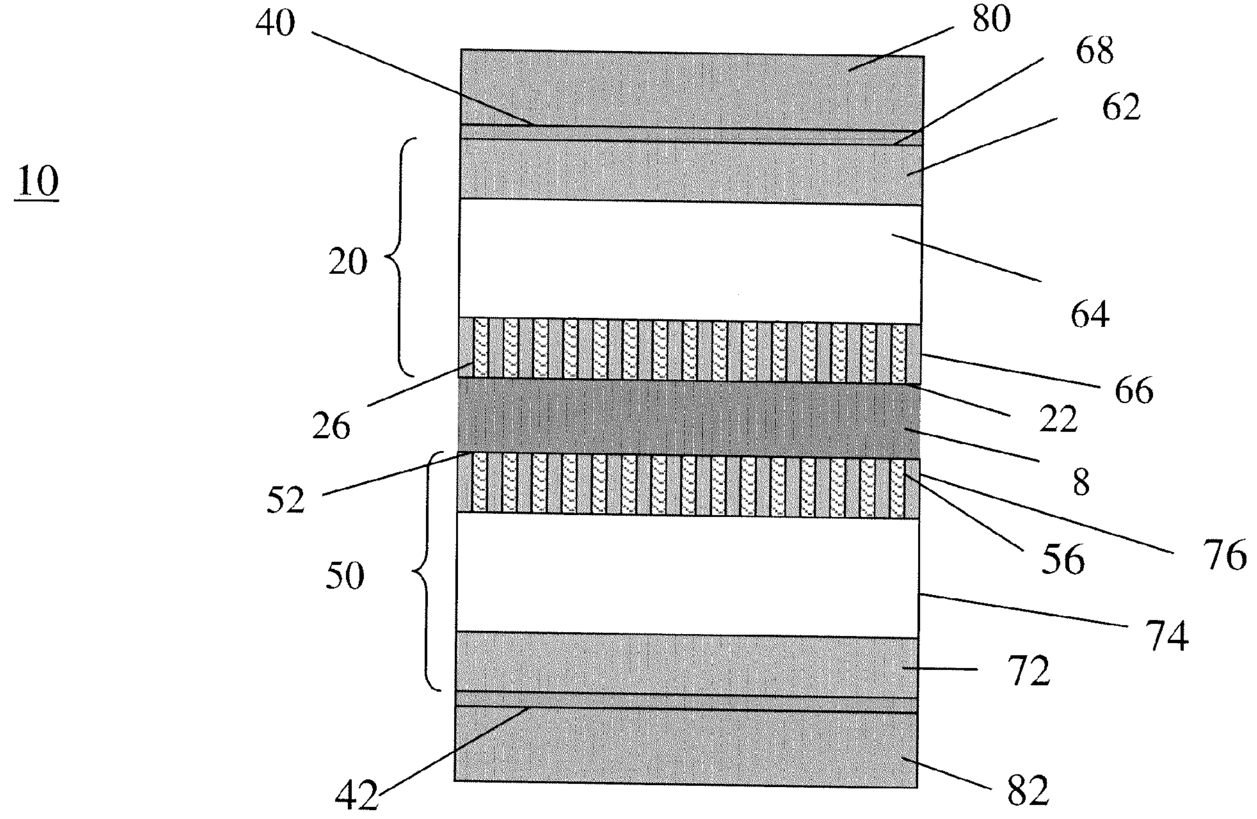


FIG. 3

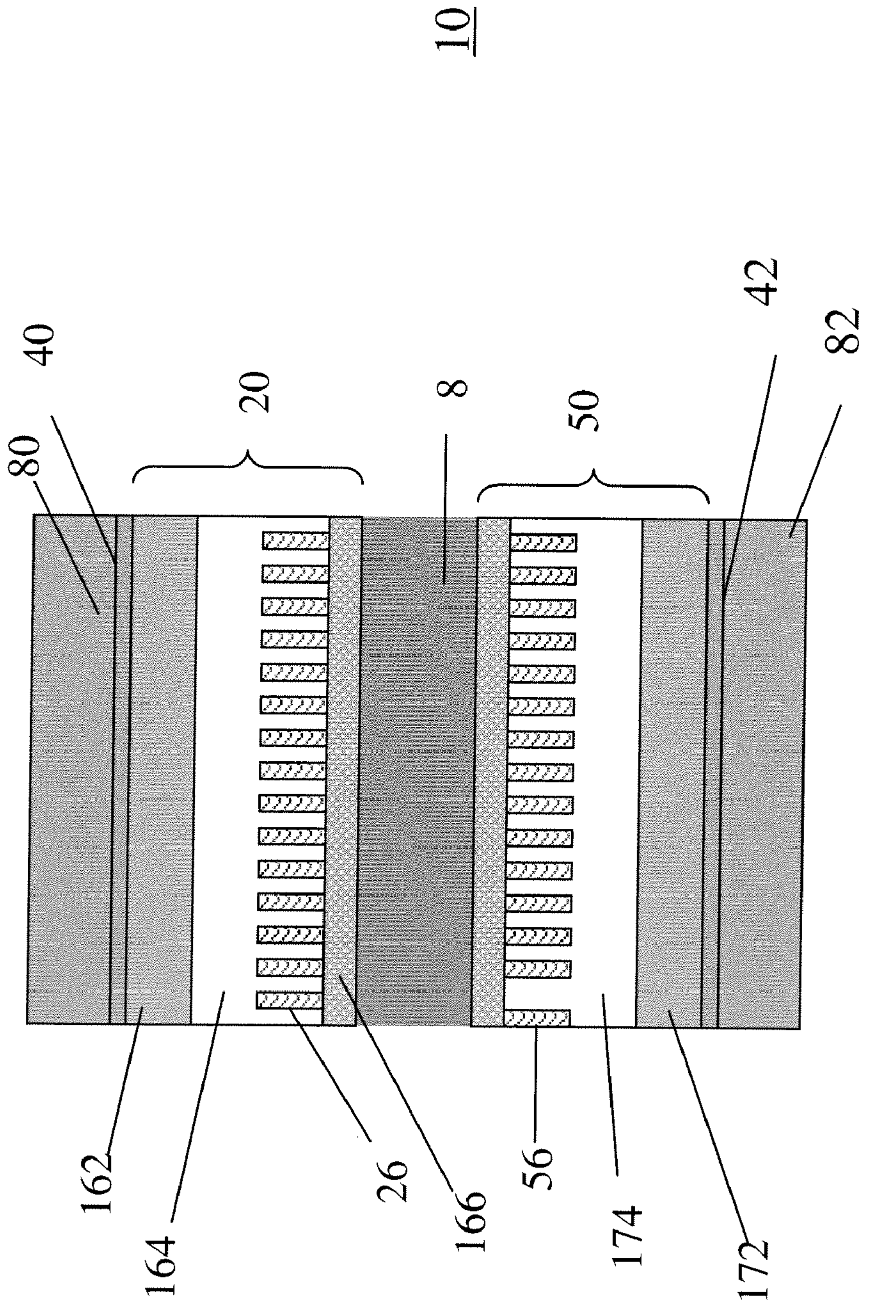


Figure 4

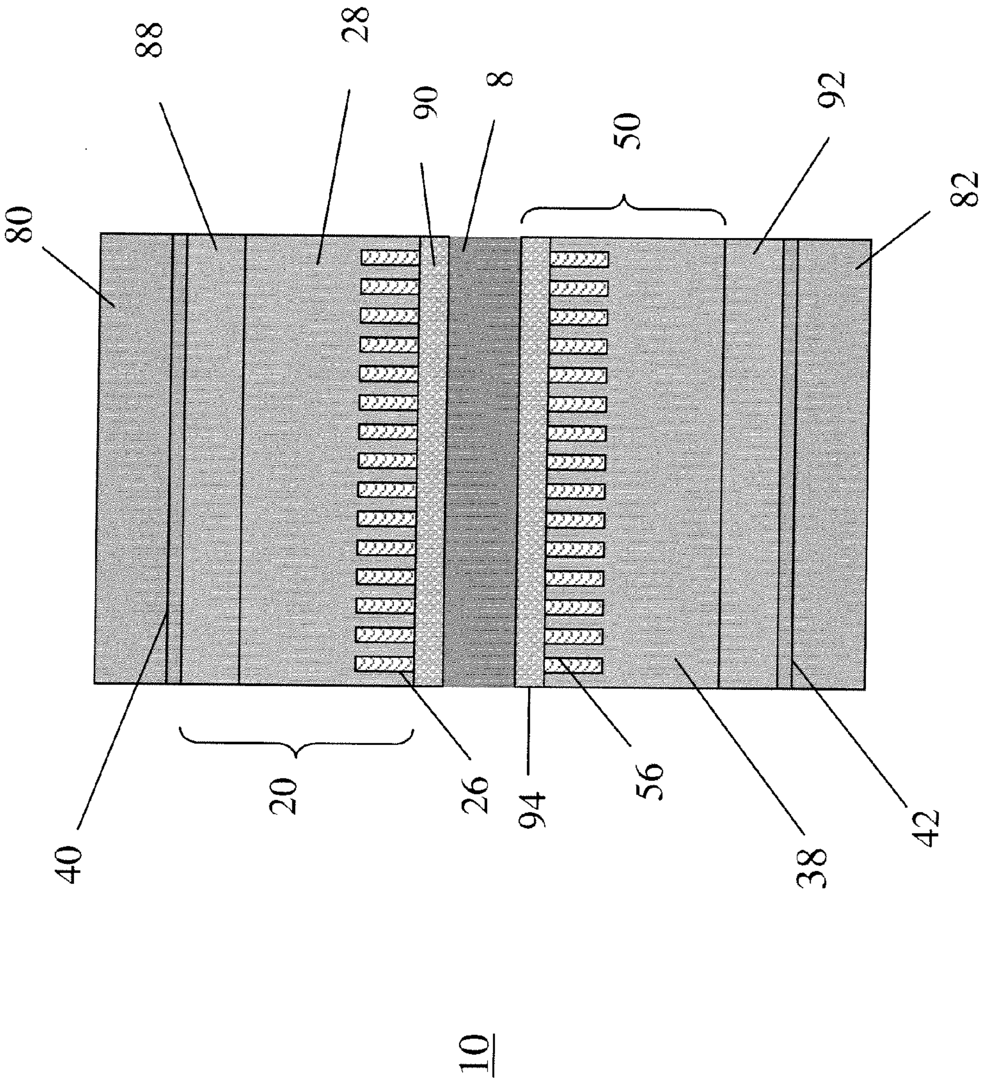


FIG. 5

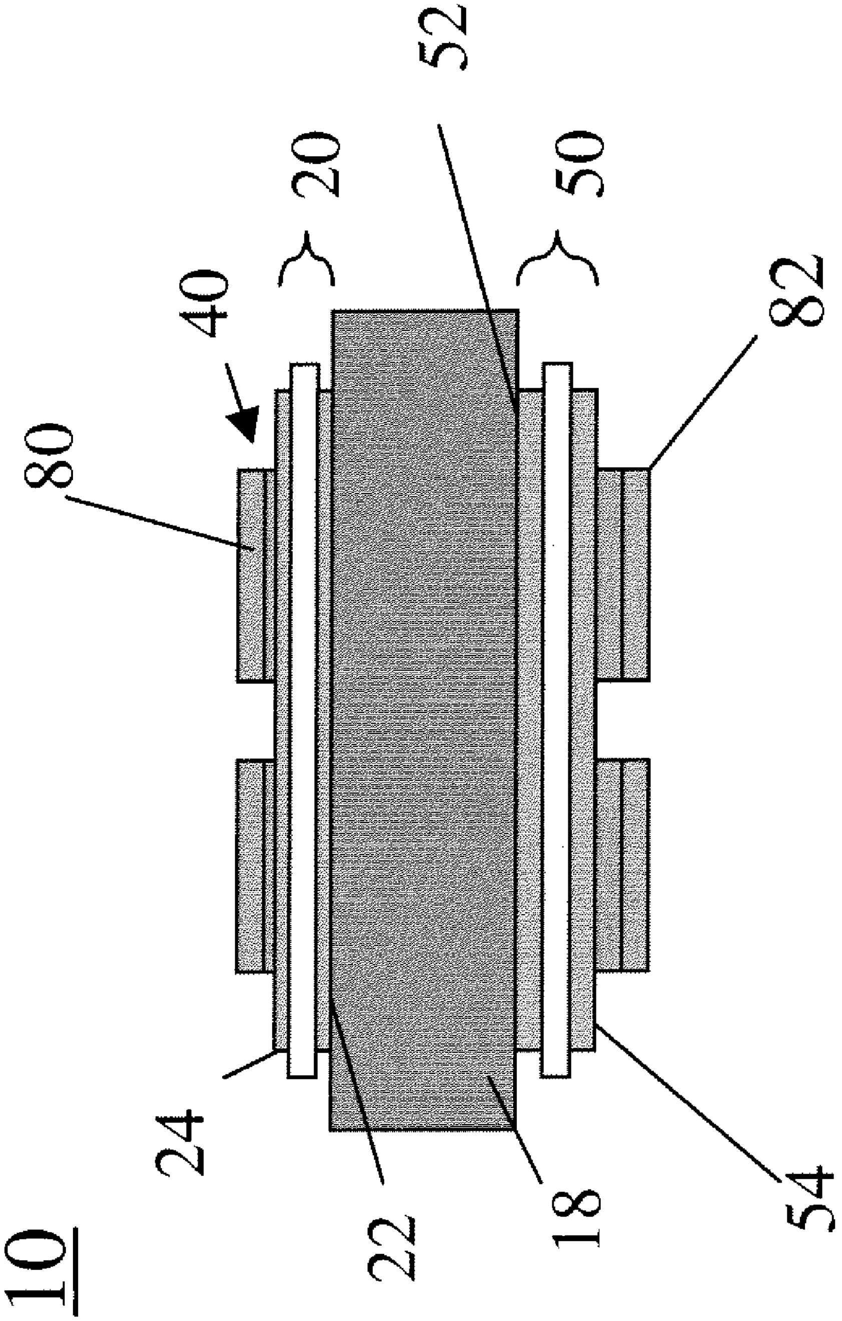


FIG. 6

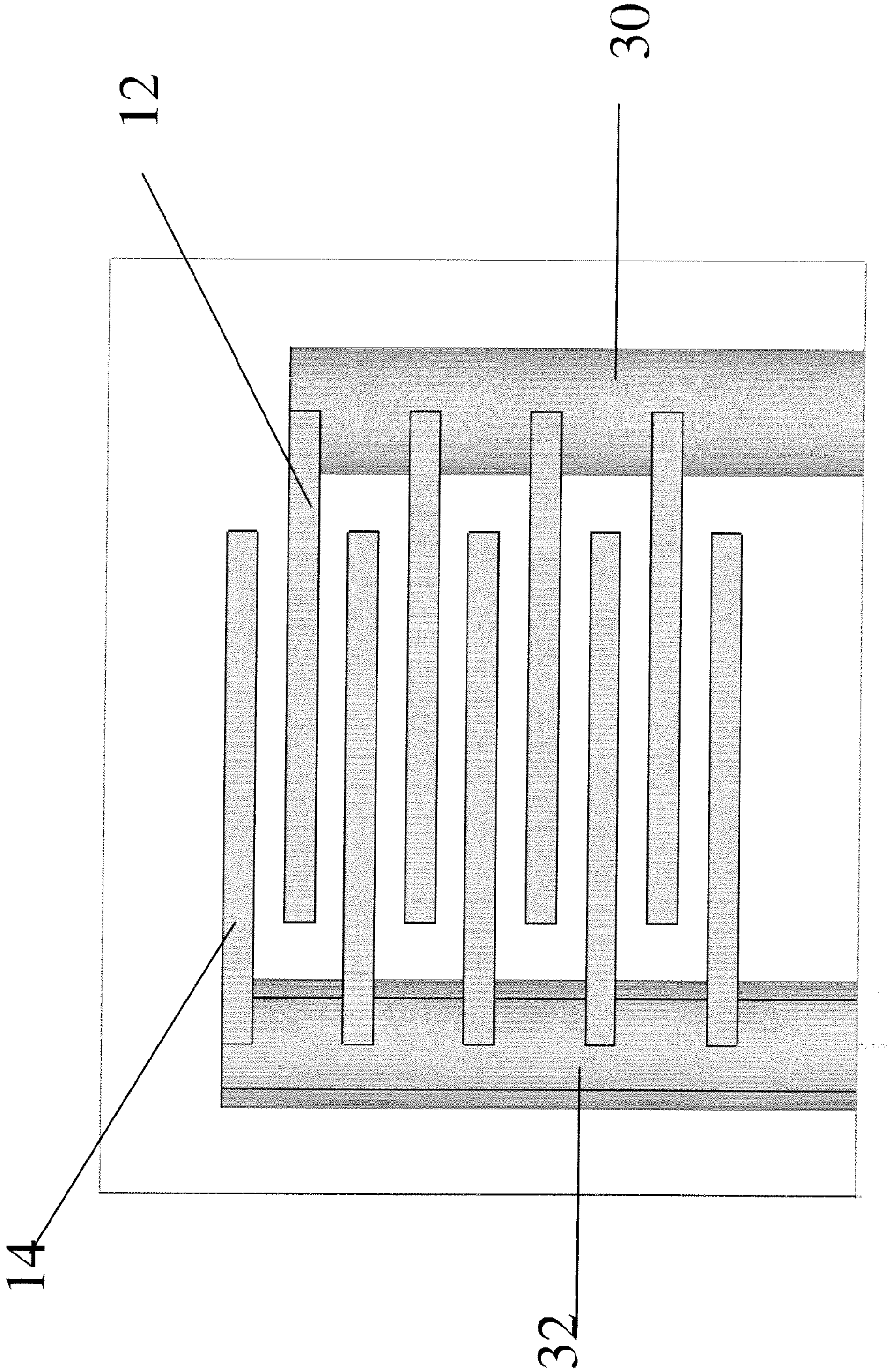


FIG. 7

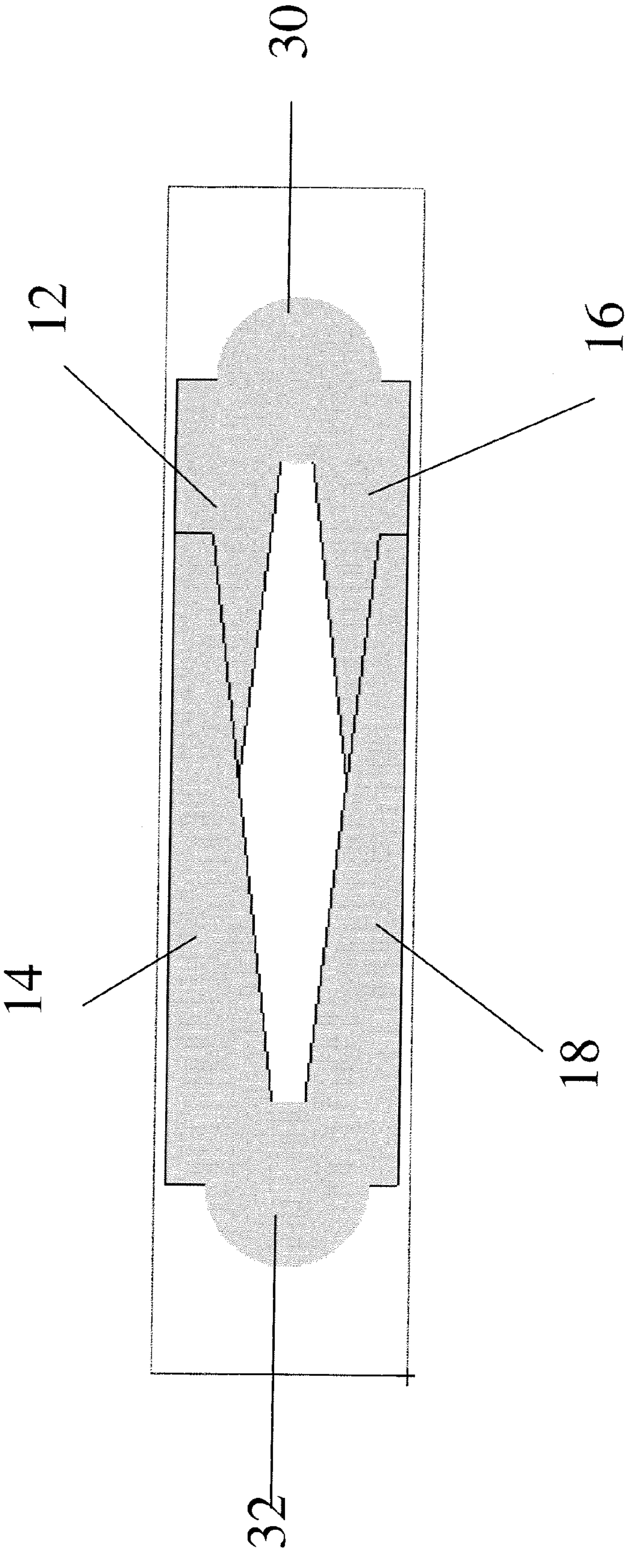


FIG. 8

DOUBLE SIDED HEAT SINK WITH MICROCHANNEL COOLING

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation in part of U.S. patent application Ser. No. 10/998,707, Stevanovic et al., entitled "Heat sink with microchannel cooling for power devices," which patent application is incorporated by reference herein in its entirety.

BACKGROUND

[0002] The invention relates generally to an apparatus for cooling a heated surface and, more particularly, to a heat sink with microchannel cooling for semiconductor power devices.

[0003] The development of higher-density power electronics has made it increasingly more difficult to cool power semiconductor devices. With modern silicon-based power devices capable of dissipating up to 500 W/cm^2, there is a need for improved thermal anagement solutions. When device temperatures are limited to 50K increases, natural and forced-air cooling schemes can only handle heat fluxes up to about one (1) W/cm^2. Conventional liquid cooling plates can achieve heat fluxes on the order of a twenty (20) W/cm^2. Heat pipes, impingement sprays, and liquid boiling are capable of larger heat fluxes, but these techniques can lead to manufacturing difficulties and high cost.

[0004] An additional problem encountered in conventional cooling of high heat flux power devices is non-uniform temperature distribution across the heated surface. This is due to the non-uniform cooling channel structure, as well as the temperature rise of the cooling fluid as it flows through long channels parallel to the heated surface.

[0005] One promising technology for high performance thermal management is microchannel cooling. In the 1980's, it was demonstrated as an effective means of cooling silicon integrated circuits, with designs demonstrating heat fluxes of up to 1000 W/cm^2 and surface temperature rise below 100° C.

[0006] U.S. patent application Ser. No. 10/998,707, Stevanovic et al. discusses drawbacks associated with a number of known heat sink designs. As discussed in Stevanovic et al., desired heat sink properties include improved thermal performance, relatively simple assembly to reduce manufacturing cost, and scalability for accommodating small and large power devices as well as different numbers of power devices. In addition, it would be desirable for the apparatus to provide electrical isolation between high power devices and the coolant. Moreover, volume and weight are important limitations in many power electronics applications, so compact heat exchangers are desired.

BRIEF DECSRIPTION

[0007] One aspect of the present invention resides in an apparatus for cooling at least two heated surfaces. The apparatus includes a base plate defining a number of upper and lower supply manifolds and a number of upper and lower exhaust manifolds. The upper and lower supply manifolds are configured to receive a coolant, and the upper and lower exhaust manifolds are configured to exhaust the coolant. The upper (lower) supply and exhaust manifolds are interleaved. The apparatus further includes an upper substrate having an inner surface and an outer surface. The inner surface is coupled to the base plate and defines a number of microchannels configured to receive the coolant from the upper supply manifolds and to deliver the coolant to the upper exhaust manifolds. The microchannels are oriented substantially perpendicular to the upper supply and exhaust manifolds. The outer surface is in thermal contact with one of the heated surfaces. The apparatus further includes a lower substrate having an inner surface and an outer surface. The inner surface is coupled to the base plate and defines a number of microchannels configured to receive the coolant from the lower supply manifolds and to deliver the coolant to the lower exhaust manifolds. The microchannels are oriented substantially perpendicular to the lower supply and exhaust manifolds. The outer surface is in thermal contact with another of the heated surfaces. The apparatus further includes a supply plenum configured to supply the coolant to the upper and lower supply manifolds and an exhaust plenum configured to exhaust the coolant from the upper and lower exhaust manifolds. The supply plenum and exhaust plenum are oriented in a plane of base plate.

[0008] Another aspect of the present invention resides in an apparatus for cooling at least two heated surfaces. The apparatus includes a base plate, as described above. The apparatus further includes an upper substrate comprising a top layer, an insulating layer and an inner layer. The inner layer defines a number of microchannels, described above. The insulating layer is disposed between the top and inner layers, the inner layer is coupled to the base plate, and the top layer is in thermal contact with one of the heated surfaces. The apparatus further includes a lower substrate comprising a bottom layer, a second insulating layer and a second inner layer. The second inner layer defines a number of microchannels, described above. The second insulating layer is disposed between the bottom and second inner layers, the second inner layer is coupled to the base plate, and the bottom layer is in thermal contact with another of the heated surfaces. The apparatus further includes a supply plenum and an exhaust plenum, as described above.

[0009] Yet another aspect of the present invention resides in an apparatus for cooling at least two heated surfaces. The apparatus includes a base plate, as described above. The apparatus further includes an upper substrate that includes a top layer and an insulating microchannel layer. The insulating microchannel layer defines a number of microchannels, described above. The insulating microchannel layer is disposed between the top layer and the base plate, and the top layer is thermally coupled to one of the heated surfaces. The apparatus further includes a lower substrate that includes a bottom layer and an insulating microchannel layer. The insulating microchannel layer defines a number of microchannels, described above. The insulating microchannel layer is disposed between the bottom layer and the base plate, and the bottom layer is thermally coupled to another of the heated surfaces. The apparatus further includes a supply plenum and an exhaust plenum, as described above.

DRAWINGS

[0010] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0011] FIG. **1** is a perspective view of an apparatus for cooling at least two heated surfaces;

[0012] FIG. **2** shows interleaved upper and lower supply and exhaust manifolds within a base plate of the apparatus of FIG. **1**;

[0013] FIG. **3** depicts, in cross-sectional view, an exemplary heat-sink with microchannels formed in the inner surfaces of the upper and lower substrates;

[0014] FIG. **4** depicts, in cross-sectional view, an exemplary heat-sink with microchannels formed in insulating microchannel layers;

[0015] FIG. **5** depicts, in cross-sectional view, an exemplary heat-sink for use with low-voltage devices;

[0016] FIG. **6** illustrates in side view a double-sided heat sink apparatus for cooling multiple power devices;

[0017] FIG. **7** is a top view of the manifolds for the double-sided heat sink module of FIGS. **2** and **3**; and

[0018] FIG. **8** is a side view of the manifolds for the double-sided heat sink module of FIG. **7**.

DETAILED DESCRIPTION

[0019] An apparatus **10** (for example a heat sink) for cooling at least two heated surfaces **42**, **44** is described first with reference to FIGS. **1**, **2** and **6**. As shown, for example in FIGS. **1** and. **6**, the apparatus **10** includes a base plate **8**, which is shown in greater detail in FIG. **2**. As shown, for example, in FIG. **2**, the base plate **8** defines a number of upper supply manifolds **12**, a number of upper exhaust manifolds **14**, a number of lower supply manifolds **16** and a number of lower exhaust manifolds **18**. The upper and lower supply manifolds **12**, **16** are configured to receive a coolant, and the upper and lower exhaust manifolds **14**, **18** are configured to exhaust the coolant. As indicated, the upper supply and exhaust manifolds **12**, **14** are interleaved, and the lower supply and exhaust manifolds **16**, **18** are interleaved. For the illustrated embodiments, the supply manifolds **12**, **14**, **16** and **18** are oriented in a plane of the base plate **8**.

[0020] As shown for example in FIG. **6**, the apparatus **10** further includes an upper substrate **20** having an inner surface **22** and an outer surface **24**. The inner surface **22** is coupled to the base plate **8**. As indicated, for example in FIG. **3**, the inner surface **22** defines a number of microchannels **26** configured to receive the coolant from the upper supply manifolds **12** and to deliver the coolant to the upper exhaust manifolds **14**. The microchannels **26** are oriented substantially perpendicular to the upper supply and exhaust manifolds **12**, **14**, as indicated in FIG. **1**, for example. The outer surface **24** is thermally coupled to one of the heated surfaces **40**, as indicated in FIG. **6**, for example.

[0021] As shown for example in FIG. **6**, the apparatus **10** further includes a lower substrate **50** having an inner surface **52** and an outer surface **54**. The inner surface **52** is coupled to the base plate **8**. As indicated, for example, in FIG. **3**, the inner surface **52** defines a number of microchannels **56** configured to receive the coolant from the lower supply manifolds **16** and to deliver the coolant to the lower exhaust manifolds **18**. The microchannels **56** are oriented substantially perpendicular to the lower supply and exhaust manifolds **16**, **18**. The outer surface **24** is thermally coupled to another of the heated surfaces **44**, as indicated in FIG. **6**, for example.

[0022] For the illustrated embodiment, the apparatus **10** further includes a supply plenum **30** configured to supply the coolant to the upper and lower supply manifolds **12**, **16** and an exhaust plenum **32** configured to exhaust the coolant from the upper and lower exhaust manifolds **14**, **18**. As indicated, for example, in FIG. **2**, the supply plenum **30** and the exhaust plenum **32** are oriented in a plane of the base plate **8**.

[0023] In operation, the microchannels **26**, **56** provide the link between the supply and exhaust manifolds. This provides the beneficial heat transfer performance of microchannels with a controlled pressure loss between the manifolds. Moreover, the use of two independent sets of supply and exhaust manifolds, one for cooling an upper power device(s) **80** and the other for cooling a lower power device(s) **82**, which are interdigitated, permits coolant to uniformly pass to the top and bottom of the module **10**. By attaching the microchannel substrates **20**, **50** to the top and bottom of the module, the heat exchanger is closed, permitting cooling on two surfaces using a heat exchanger volume previously used to cool only one surface.

[0024] In non-limiting examples, the heated surfaces correspond to power devices, non-limiting examples of which include Insulated Gate Bipolar Transistors (IGBT), Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Diodes, Metal Semiconductor Field Effect Transistors (MESFET), and High Electron Mobility Transistors (HEMT). Those skilled in the art will recognize that these are examples of power devices and that the invention is by no means limited to these examples. Rather, apparatus **10** may be used to cool these or other power devices.

[0025] As used herein the phrase "oriented substantially perpendicular" should be understood to mean that the microchannels **26** (**56**) are oriented at angles of about ninety degrees plus/minus about thirty degrees (90+/−30 degrees) relative to the inlet and outlet manifolds **12**, **14** (**16**, **18**). According to a more particular embodiment, the microchannels **26** (**56**) are oriented at angles of about ninety degrees plus/minus about fifteen degrees (90+/−15 degrees) relative to the inlet and outlet manifolds **12**, **14** (**16**, **18**).

[0026] Many coolants can be employed for apparatus **10**, and the invention is not limited to a particular coolant. Exemplary coolants include water, ethylene-glycol, oil, aircraft fuel and combinations thereof. According to a particular embodiment, the coolant is a single phase liquid. In operation, the coolant enters the manifolds **12**, **16** in base plate **8** and flows through microchannels **26**, **56** before returning through exhaust manifolds **14**, **18**. More particularly, coolant enters supply plenum **30**, whose fluid diameter exceeds that of the other channels in apparatus **10**, according to a particular embodiment, so that there is no significant pressure-drop in the plenum. For example, the fluid diameter of supply plenum **30** exceeds that of the other channels by a ratio of about three-to-one (3:1) relative to the manifold hydraulic diameter. For this example, the difference in the pressure drop for a single plenum channel (of equal length) would be of the order of 1/(3^5)=1/243 of the loss of the loss in the manifold. The coolant exits apparatus **10** through exhaust plenum **32**. It should be noted that this simple example assumes that all of the flow passes from one plenum to one manifold, so that the pressure scales at the ratio given above. In the illustrated embodiments of the present invention, however, there are multiple manifolds branching off of a single plenum. Accordingly, the increased number of channels partly tempers the increased pressure loss due to reduced flows in each channel.

[**0027**] According to a particular embodiment, base plate **8** comprises a thermally conductive material. Exemplary materials include copper, Kovar, Molybdenum, titanium, ceramics and combinations thereof. The invention is not limited to specific base plate materials.

[**0028**] Exemplary microchannel **26**, **56** configurations are discussed and illustrated in U.S. patent application Ser. No. 10/998,707, referenced above.

[**0029**] The inlet and outlet configuration for the base plate **8** affects the heat transfer effectiveness of the apparatus **10**. For the exemplary arrangement shown in FIG. **8**, each of the upper and lower supply manifolds **12**, **16** is tapered such that a cross-section of the respective upper or lower supply manifold is larger at the supply plenum than at the exhaust plenum. In addition, for the exemplary arrangement shown in FIGS. **2** and **8**, each of the upper and lower supply manifolds **12**, **16** extends from the supply plenum **30** and is oriented substantially perpendicular to the supply plenum **30**. As discussed in U.S. patent application Ser. No. 10/998,707, referenced above, dimensional factors may be tailored to enhance thermal performance. For example, in particular embodiments, the upper and lower supply manifolds **12**, **16** are characterized by a width in a range of about 0.5 mm to about 1 mm. According to a particular embodiment, the upper and lower supply manifolds **12**, **16** are about 0.5 mm wide.

[**0030**] For the exemplary arrangement shown in FIG. **8**, each of the upper and lower exhaust manifolds **14**, **18** is tapered such that a cross-section of the respective upper or lower exhaust manifold is larger at the exhaust plenum than at the supply plenum. In addition, for the exemplary arrangement shown in FIGS. **2** and **8**, each of the upper and lower exhaust manifolds **14**, **18** extends from the exhaust plenum **32** and is oriented substantially perpendicular to the exhaust plenum **32**. In particular embodiments, the upper and lower exhaust manifolds are characterized by a width in a range of about 0.5 mm to about 1 mm. According to a particular embodiment, the upper and lower exhaust manifolds are about 0.5 mm wide.

[**0031**] FIG. **7** is a top view of the manifolds of FIG. **2**. For the exemplary embodiment illustrated in FIG. **7**, the number of the upper supply and exhaust manifolds **12**, **14** differ by one. However, the example shown in FIG. **7**, in which there are four upper supply manifolds **12** and five upper exhaust manifolds **14**, is merely illustrative. Similarly, for certain embodiments, the number of the lower supply and exhaust manifolds **16**, **18** differ by one. For the illustrated embodiments, the supply plenum **30** and the exhaust plenum **32** are substantially uniform in cross-section. In other embodiments, the supply plenum **30** and the exhaust plenum **32** are tapered. In non-limiting examples, the coolant is selected from the group consisting of water, ethylene-glycol, oil, aircraft fuel and combinations thereof. The apparatus **10** accommodates cooling with single phase flow, such as impingement or cross-flow cooling. The apparatus **10** also accommodates cooling with two-phase flow, such as boiling or spray cooling. Dielectric fluids, such as FC-72, HFE7100 and conductive fluids such as water can be used as the coolant, depending upon the design of the jet and the packaging.

[**0032**] Depending on the thickness of the heat sink module **10**, the top and bottom side manifolds may need to be offset and staggered. In which case, the lengths of the individual microchannel links would be longer relative to the single-sided module described in U.S. patent application Ser. No. 10/998,707, referenced above, but would permit double-sided cooling. For the illustrated embodiment of FIGS. **1**, **2** and **7**, the upper and lower supply manifolds **12**, **16** are offset, and the upper and lower exhaust manifolds **14**, **18** are offset. For certain other embodiments, the upper supply manifolds **12** are aligned with one of the lower exhaust and supply manifolds **18**, **16**, and the upper exhaust manifolds **14** are aligned with the other of the lower exhaust and supply manifolds **18**, **16**.

[**0033**] For the exemplary embodiments of FIGS. **3** and **4**, the upper and lower substrates **20**, **50** comprise at least one thermally conductive material and at least one electrically isolating material. According to particular embodiments, substrates **20**, **50** are formed of either a direct bonded copper (DBC) or an active metal braze (AMB) structure. DBC and AMB refer to processes by which copper layers are directly bonded to a ceramic substrate. Exemplary ceramic bases include aluminum-oxide (AL_2O_3), aluminum nitride (AIN), berilium oxide (BeO) and silicon nitride (Si_3N_4). Both DBC and AMB are convenient structures for substrates **20**, **50** and the use of the same conductive material (in this case, copper) on both sides of the ceramic base provides thermal and mechanical stability. Of course, substrates **20**, **50** can be constructed from other materials, such as gold or silver. Beneficially, the substrates **20**, **50** can be attached to base plate **8** using any one of a number of techniques, including brazing, bonding, diffusion bonding, soldering, or pressure contact such as clamping. This provides a simple assembly process, which reduces the overall cost of the apparatus **10**. Moreover, by attaching the substrates **20**, **50** to base plate **8**, fluid passages are formed under the upper and lower heated surfaces **40**, **42**, enabling practical and cost-effective implementation of the microchannel cooling technology.

[**0034**] For the exemplary embodiment illustrated in FIG. **3**, the upper substrate **20** comprises a top layer **62**, an insulating layer **64** and an inner layer **66**. For this embodiment, the microchannels **26** are formed in the inner layer **66**, and the insulating layer **64** is disposed between the top layer **62** and the inner layer. The inner layer **66** is attached to the base plate **8**, and the top layer is coupled to one of the heated surfaces **42**. For example, the inner layer **66** is attached to the base plate **8** by brazing, bonding, diffusion bonding, soldering, pressure contact such as clamping or other attachment means. For the exemplary embodiment of FIG. **3**, the heated surface **40** is coupled to the top layer **62** by solder **68**, as shown. For the exemplary embodiment depicted in FIG. **3**, microchannels **26** extend through the inner layer **66**. In other words, the microchannel depth is equal to the thickness of the inner layer **66**. CFD modeling results demonstrated improved performance for tall, high-aspect ratio microchannels, such as those shown in FIG. **3**. For a typical thickness of the inner layer of a substrate, the microchannels in FIG.

3 would be about 0.3 mm tall. Of course other implementations are possible, and for an alternative embodiment (not shown) the microchannels **26** do not extend through the thickness of the inner layer **66**, thereby isolating the insulating layer **64** from the coolant, which flows through microchannels **26**. Beneficially, the ceramic layer **64** provides electrical isolation between the coolant and the power devices **80** mounted atop substrate **20**. According to a particular embodiment, top layer **62** and inner layer **66** are formed of copper (Cu), and insulating layer **64** is a ceramic selected from the group consisting of AlN, Al_2O_3, Si_3N , BeO or combinations thereof. According to a more particular embodiment, the microchannels **26** are formed in the copper layer **66** on the underside of a substrate **20**.

[**0035**] For the lower portion of the arrangement shown in FIG. **3**, the lower substrate **50** comprises a bottom layer **72**, a second insulating layer **74** and a second inner layer **76**. For this embodiment, the microchannels **56** are formed in the second inner layer **76**, and the second insulating layer **74** is disposed between the bottom layer **72** and the second inner layer **76**. The second inner layer is attached to the base plate **8**, and the bottom layer is coupled to another of the heated surfaces **44**. For the illustrated embodiment, the lower substrate **50** is similar in construction, dimensions and materials to the upper substrate **50**. Reference number **82** indicates power devices mounted on substrate **50**, and reference number **58** indicates a solder layer for coupling the heated surface **44** of the power device **82** to the bottom layer **72**.

[**0036**] Another exemplary embodiment is shown in FIG. **4**. For this embodiment, the upper substrate **20** includes a top layer **162** and an insulating microchannel layer **164**, and the microchannels **26** are formed in the insulating microchannel layer **162**. The insulating microchannel layer **164** is disposed between the top layer **162** and the base plate **8**, and the top layer **162** is coupled to one of the heated surfaces **42** of the power device(s) **80**. As shown in FIG. **4**, the microchannels **26** do not extend through insulating microchannel layer **164**, in order to isolate the coolant from the heated surface **42** of the power device(s) **80**. More particularly, the remaining ceramic layer acts as a dielectric barrier between power devices **80** atop substrate **20** and the coolant. Beneficially, while maintaining electrical isolation, this embodiment also eliminates the thickness of material between the power devices **80**, **82** and the coolant, resulting in improved thermal performance.

[**0037**] For the lower portion of the arrangement shown in FIG. **4**, the lower substrate **50** includes a bottom layer **172** and an insulating microchannel layer **174**, and the microchannels **56** are formed in the insulating microchannel layer **174**. As shown, the insulating microchannel layer **174** is disposed between the bottom layer **172** and the base plate **8**, and the bottom layer **172** is coupled to another of the heated surfaces **44** of the power device(s) **82**. For the illustrated embodiment, the construction and materials of the lower substrate **50** are similar to that of the upper substrate **20**. According to a more particular embodiment, upper substrate **20** further includes a lower layer **166** disposed between and attached to the insulating microchannel layer **164** and the base plate **8**, as shown for example in FIG. **4**. For this particular embodiment, lower substrate **50** further includes an upper layer **176** disposed between and attached to the insulating microchannel layer **174** and the base plate **8**, as shown for example in FIG. **4**. Exemplary materials for the lower layer **76** and upper layer **176** include copper.

[**0038**] Another embodiment is shown in FIG. **5**. For this embodiment, the upper substrate **20** includes an inner layer **28**, and microchannels **26** are formed in and extend partially through the inner layer **28**. As shown in FIG. **5**, the lower substrate **50** includes a second inner layer **38**, and microchannels **56** are formed in and extend partially through the second inner layer **38**. Exemplary materials for the inner layers **28**, **38** include but are not limited to copper, molybdenum, aluminum, composite materials such as aluminum silicon carbide (AlSiC) and aluminum graphite composites, for example the material sold under the tradename Metgraf™, as well as alloys, such as cobalt-nickel ferrous alloys, for example the material sold under the tradename Kovar™. In other applications, ceramics or silicon may be used to form inner layers **28**, **38**. For particular embodiments, the microchannels **26**, **56** extend through the respective ones of the inner layers **28**, **38**, and the microchannels are less than about 200 μm wide and are separated by a number of gaps of less than about 200 μm. This embodiment is adapted for use with low voltage devices such as laser diodes, RF power devices and computer chips. For this embodiment, the upper substrate **20** may further include a top layer **88** and a lower layer **90**, and the lower substrate **50** may further include a bottom layer **92** and an upper layer **94**, as shown. In one non-limiting example, the top layer **88** of the upper substrate and the bottom layer **92** of the lower substrate are formed of copper. Exemplary materials for the lower layer **90** of the upper substrate and for the upper layer **94** of the lower substrate include but are not limited to copper, molybdenum, aluminum, composite materials such as aluminum silicon carbide (AlSiC) and aluminum graphite composites, for example the material sold under the tradename Metgraf™, as well as alloys, such as cobalt-nickel ferrous alloys, for example the material sold under the tradename Kovar™. In other applications, ceramics or silicon may be used to form lower and upper layers **90**, **94**.

[**0039**] Benefits of the double sided heat-sink module include reduction of weight, volume and number of heat sinks required. Other benefits of the invention include improved heat transfer due to increased surface areas and heat transfer coefficients for small, densely packed channels. In addition, the invention provides controlled pressure losses, due to the manifolding structure, for which the effective microchannel length is reduced to the distance between adjacent manifolds. Further, relatively uniform microchannel velocities are achieved by using a tapered manifold structure. Further, the invention enables simpler heat sink manufacturing processes, by reducing the number of bonds to the bond between the substrates and the base plate.

[**0040**] Although only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

1. An apparatus for cooling at least two heated surfaces, said apparatus comprising:

a base plate defining a plurality of upper supply manifolds, a plurality of upper exhaust manifolds, a plurality of lower supply manifolds and a plurality of lower exhaust manifolds, wherein said upper and lower supply manifolds are configured to receive a coolant, wherein said upper and lower exhaust manifolds are configured to exhaust the coolant, wherein said upper supply and exhaust manifolds are interleaved, and wherein said lower supply and exhaust manifolds are interleaved;

an upper substrate having an inner surface and an outer surface, wherein said inner surface is coupled to said base plate, wherein said inner surface defines a plurality of microchannels configured to receive the coolant from said upper supply manifolds and to deliver the coolant to said upper exhaust manifolds, wherein said microchannels are oriented substantially perpendicular to said upper supply and exhaust manifolds, and wherein said outer surface is in thermal contact with one of the heated surfaces;

a lower substrate having an inner surface and an outer surface, wherein said inner surface is coupled to said base plate, wherein said inner surface defines a plurality of microchannels configured to receive the coolant from said lower supply manifolds and to deliver the coolant to said lower exhaust manifolds, wherein said microchannels are oriented substantially perpendicular to said lower supply and exhaust manifolds, and wherein said outer surface is in thermal contact with another of the heated surfaces;

a supply plenum configured to supply the coolant to said upper and lower supply manifolds; and

an exhaust plenum configured to exhaust the coolant from said upper and lower exhaust manifolds, wherein said supply plenum and said exhaust plenum are oriented in a plane of said base plate.

2. The apparatus of claim 1, wherein said microchannels are about 100 μm wide, and wherein said gaps are about 100 μm.

3. The apparatus of claim 1, wherein each of said upper and lower supply manifolds is tapered such that a cross-section of the respective upper or lower supply manifold is larger at said supply plenum than at said exhaust plenum.

4. The apparatus of claim 3, wherein each of said upper and lower supply manifolds extends from said supply plenum and is oriented substantially perpendicular to said supply plenum.

5. The apparatus of claim 1, wherein each of said upper and lower exhaust manifolds is tapered such that a cross-section of the respective upper or lower exhaust manifold is larger at said exhaust plenum than at said supply plenum.

6. The apparatus of claim 5, wherein each of said upper and lower exhaust manifolds extends from said exhaust plenum and is oriented substantially perpendicular to said exhaust plenum.

7. The apparatus of claim 1, wherein a number of said upper supply manifolds and a number of said upper exhaust manifolds differ by one, and wherein a number of said lower supply manifolds and a number of said lower exhaust manifolds differ by one.

8. The apparatus of claim 1, wherein said upper supply manifolds are aligned with one of said lower exhaust and supply manifolds, and wherein said upper exhaust manifolds are aligned with the other of said lower exhaust and supply manifolds.

9. The apparatus of claim 1, wherein said upper and lower supply manifolds are offset, and wherein said upper and lower exhaust manifolds are offset.

10. The apparatus of claim 1, wherein said base plate comprises a thermally conductive material.

11. The apparatus of claim 10, wherein each of said upper and lower substrates comprises at least one thermally conductive material.

12. The apparatus of claim 11, wherein each of said upper and lower substrates comprises at least one electrically isolating material.

13. The apparatus of claim 11, wherein at least one of said upper and lower substrates comprises a direct bonded copper structure.

14. The apparatus of claim 11, wherein at least one of said upper and lower substrates comprises an active metal braze (AMB) structure.

15. The apparatus of claim 1, wherein said upper substrate comprises a top layer, an insulating layer and an inner layer, wherein said microchannels are formed in said inner layer, wherein said insulating layer is disposed between said top layer and said inner layer, wherein said inner layer is attached to said base plate, and wherein said top layer is coupled to one of the heated surfaces, and

wherein said lower substrate comprises a bottom layer, a second insulating layer and a second inner layer, wherein said microchannels are formed in said second inner layer, wherein said second insulating layer is disposed between said bottom layer and said second inner layer, wherein said second inner layer is attached to said base plate, and wherein said bottom layer is coupled to another of the heated surfaces.

16. The apparatus of claim 1, wherein said upper substrate comprises a top layer and an insulating microchannel layer, wherein said microchannels are formed in said insulating microchannel layer, wherein said insulating microchannel layer is disposed between said top layer and said base plate, and wherein said top layer is coupled to one of the heated surfaces,

wherein said lower substrate comprises a bottom layer and an insulating microchannel layer, wherein said microchannels are formed in said insulating microchannel layer, wherein said insulating microchannel layer is disposed between said bottom layer and said base plate, and wherein said bottom layer is coupled to another of the heated surfaces.

17. The apparatus of claim 1, wherein said upper substrate comprises an inner layer, wherein said microchannels are formed in and extend partially through said inner layer,

wherein said lower substrate comprises a second inner layer, wherein said microchannels are formed in and extend partially through said inner layer.

18. The heat sink of claim 17, wherein said microchannels extend through the respective ones of said inner layers, and wherein said microchannels are less than about 200 μm wide and are separated by a plurality of gaps of less than about 200 μm.

19. An apparatus for cooling at least two heated surfaces, said apparatus comprising:

a base plate defining a plurality of upper supply manifolds, a plurality of upper exhaust manifolds, a plurality of lower supply manifolds and a plurality of lower exhaust manifolds, wherein said upper and lower supply manifolds are configured to receive a coolant, wherein said upper and lower exhaust manifolds are configured to exhaust the coolant, wherein said upper supply and exhaust manifolds are interleaved, and wherein said lower supply and exhaust manifolds are interleaved;

an upper substrate comprising a top layer, an insulating layer and an inner layer, wherein said inner layer defines a plurality of microchannels configured to receive the coolant from said upper supply manifolds and to deliver the coolant to said upper exhaust manifolds, wherein said microchannels are oriented substantially perpendicular to said upper supply and exhaust manifolds, wherein said insulating layer is disposed between said top layer and said inner layer, wherein said inner layer is coupled to said base plate, and wherein said top layer is in thermal contact with one of the heated surfaces;

a lower substrate comprising a bottom layer, a second insulating layer and a second inner layer, wherein said second inner layer defines a plurality of microchannels configured to receive the coolant from said lower supply manifolds and to deliver the coolant to said lower exhaust manifolds, wherein said microchannels are oriented substantially perpendicular to said lower supply and exhaust manifolds, wherein said second insulating layer is disposed between said bottom layer and said second inner layer, wherein said second inner layer is coupled to said base plate, and wherein said bottom layer is in thermal contact with another of the heated surfaces;

a supply plenum configured to supply the coolant to said upper and lower supply manifolds; and

an exhaust plenum configured to exhaust the coolant from said upper and lower exhaust manifolds, wherein said supply plenum and said exhaust plenum are oriented in a plane of said base plate.

20. The apparatus of claim 19, wherein said microchannels extend through respective ones of said inner layers.

21. The apparatus of claim 19, wherein said top and bottom layers and said inner layers comprise copper, and wherein said insulating layers comprise a ceramic.

22. An apparatus for cooling at least two heated surfaces, said apparatus comprising:

a base plate defining a plurality of upper supply manifolds, a plurality of upper exhaust manifolds, a plurality of lower supply manifolds and a plurality of lower exhaust manifolds, wherein said upper and lower supply manifolds are configured to receive a coolant, wherein said upper and lower exhaust manifolds are configured to exhaust the coolant, wherein said upper supply and exhaust manifolds are interleaved, and wherein said lower supply and exhaust manifolds are interleaved;

an upper substrate comprising a top layer and an insulating microchannel layer, wherein said insulating microchannel layer defines a plurality of microchannels configured to receive the coolant from said upper supply manifolds and to deliver the coolant to said upper exhaust manifolds, wherein said microchannels are oriented substantially perpendicular to said upper supply and exhaust manifolds, wherein said insulating microchannel layer is disposed between said top layer and said base plate, and wherein said top layer is thermally coupled to one of the heated surfaces,

a lower substrate comprising a bottom layer and an insulating microchannel layer, wherein said insulating microchannel layer defines a plurality of microchannels configured to receive the coolant from said lower supply manifolds and to deliver the coolant to said lower exhaust manifolds, wherein said microchannels are oriented substantially perpendicular to said lower supply and exhaust manifolds, wherein said insulating microchannel layer is disposed between said bottom layer and said base plate, and wherein said bottom layer is thermally coupled to another of the heated surfaces;

a supply plenum configured to supply the coolant to said upper and lower supply manifolds; and

an exhaust plenum configured to exhaust the coolant from said upper and lower exhaust manifolds, wherein said supply plenum and said exhaust plenum are oriented in a plane of said base plate.

23. The apparatus of claim 22, wherein said upper substrate further comprises a lower layer disposed between and attached to said insulating microchannel layer and said base plate, and

wherein said lower substrate further comprises an upper layer disposed between and attached to said insulating microchannel layer and said base plate.

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